Facies and biostratigraphy of the Late Carboniferous/Early Permian sedimentary sequence in the Carnic Alps (Austria/Italy)

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In memoriam Franz Kahler (1900-1996)

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ABSTRACT

The Late Carboniferous/Early Permian sequence in the Carnic Alps (Austria/Italy) is a more than 2000 m thick succession of shallow marine clastic and carbonate sedimentary rocks. The succession unconformably overlies the folded Variscan basement and is divided into Bombaso Formation, Auernig Group, Rattendorf Group and Trogkofel Group. Auernig Group and Rattendorf Group are characterized by clastic-carbonate cycles related to Gondwana glaciocustatic sea level changes. Carbonates contain abundant fossils throughout the sequence, biostratigraphy is mainly based on fusulinids. Fine-grained clastic intervals contain abundant plant fossils, allowing a close correlation with fluvial succession of the Eastern Alps (Stangnock Formation of the Gurktal Nappe). Fusulinids of the Carnic Alps show high similarity with those of the Russian Platform, Donets Basin and Predonets Trough, Southern Urals and particularly with Central Asia. Uppermost Moscovian, Kasimovian, Gzhelian, lowermost Asselian, late Asselian, Sakmarian and Artinskian equivalents are established and precise correlation with stratotype regions have been completed. Fusulinid, conodont and plant fossil data well correspond with each other.

KEY WORDS
Peri-Tethys,
Late Carboniferous,
Early Permian,
Carnic Alps,
facies,
biostratigraphy,
fusulinids,
conodonts,
plant fossils.

RÉSUMÉ

Faciès et biostratigraphie de la séquence sédimentaire Carbonifère supérieur/Permien inférieur dans les Alpes carniques (Autriche/Italie). La séquence Carbonifère supérieur/Permien inférieur dans les Alpes carniques (Autriche/Italie) est constituée de plus de 2000 m de roches clastiques et carbonatées marines peu profondes. La succession recouvre en discordance le socle varisque plissé et est subdivisée en la Formation Bombaso, les Groupes Auernig, Rattendorf et Trogkofel. Les Groupes Auernig et Ratendorf sont caractérisés par des cycles clastiques et carbonatés produits par des variations glacio-eustatiques (Gondwana). Les carbonates contiennent des fossiles abondants tout au long de la séquence, la biostratigraphie étant principalement fondée sur les fusulines. Les intervalles clastiques fins contiennent des fossiles de plantes abondants, permettant une corrélation étroite avec la succession fluviatile des Alpes orientales (Formation Stangnock de la nappe de Gurktal). Les fusulines des Alpes carniques montrent de grande similarité avec celles de la plate-forme russe, bassins du Donetz et Predonetz, Oural du Sud et particulièrement Asie centrale. Des équivalents de la partie supérieure du Moscovien, Kasimovien, Gzhélien, de la partie inférieure de l'Assélien, de l'Asselien supérieur, du Sakmarien et de l'Artinskien ont pu être établis et une corrélation précise avec les régions stratotypes a été accomplie. Les données sur les fusulines, conodontes et plantes fossiles correspondent bien les unes aux autres.

MOTS CLÉS
Péri-Téthys,
Carbonifère supérieur,
Permien inférieur,
Alpes carniques,
faciès,
biostratigraphie,
fusulines,
conodontes,
plantes fossiles.

INTRODUCTION

In the Carnic Alps (southern Austria/northern Italy) the folded Variscan basement is unconformably overlain by a thick succession of shallow marine clastic and carbonate rocks of the Late Carboniferous Bombaso Formation and Auernig Group and the Early Permian Rattendorf and Trogkofel Group (Fig. 1). These rocks were deposited in discrete basins formed by block and wrench faulting subsequent to the Variscan orogenic phase with its climax during the Westphalian. Classic outcrops occur in the central Carnic Alps along the Austrian/Italian border (Fig. 2). Sedimentary rocks of all formations, particularly the carbonates, contain abundant fossils providing the basis for biostratigraphic subdivision and correlation. Biostratigraphy of the Late Paleozoic sequence in the Carnic Alps is mainly based on fusulinids, although plant fossils and conodonts are of importance too. During the last decades major progress has been achieved concerning sedimentology, paleontology and biostratigraphy of this sequence (see Flügel 1980 a-b, 1981; Kahler 1983, 1985, 1986, 1989; Fritz *et al.* 1990; Venturini 1990; Krainer 1992, 1993 and Forke 1995 for further informations and references). The present paper gives a summary of the Late Carboniferous/Early Permian sequence with special emphasis on the biostratigraphy and correlation with other regions.

FACIES

Bombaso Formation

The Bombaso Formation consists of poorly sorted immature breccias and conglomerates which are either predominantly composed of radiolarian chert and volcanic clasts (Pramollo Member) or of Silurian to Devonian carbonate clasts (Malinfier Horizon). Thickness ranges from a few meters up to about 200 meters. The clasts are derived from the Variscan basement of the uplifted Paleocarnic Chain. The succession of the Bombaso Formation generally shows a fining upward trend. Bioclasts of brachiopods, crinoids and fusulinids are rarely present indicating

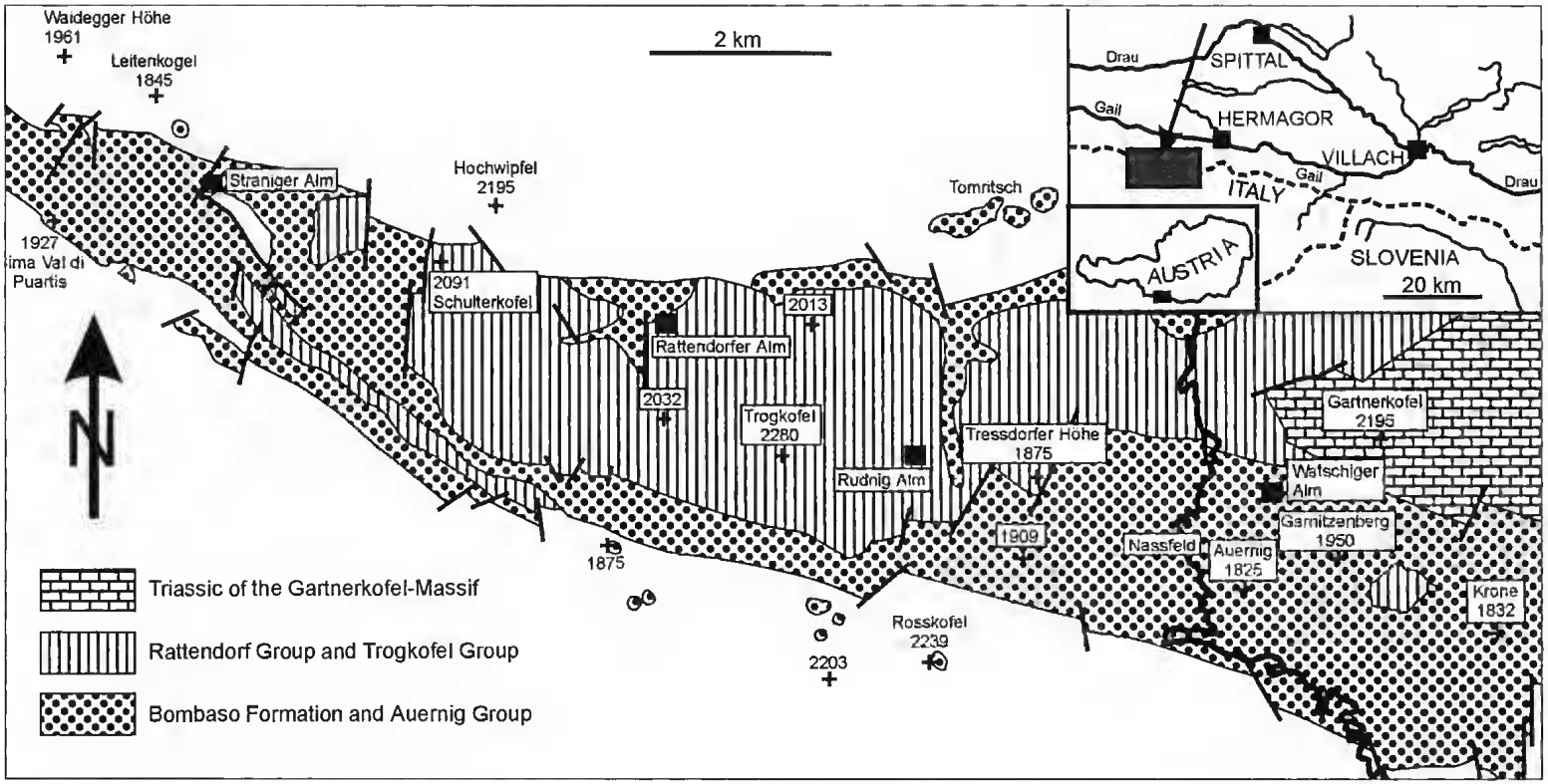


FIG. 1. — Map showing the distribution of Late Carboniferous and Early Permian sedimentary rocks in the Carnic Alps (Austria/Italy).

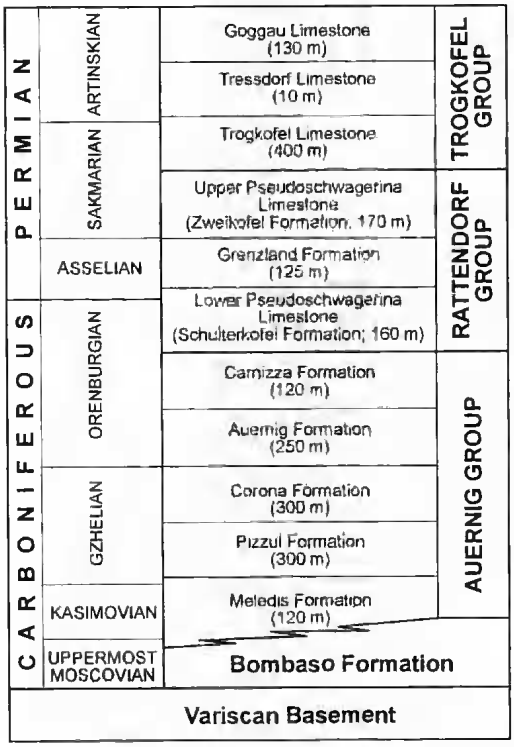


FIG. 2. — Stratigraphy of the Late Carboniferous and Early Permian strata in the Carnic Alps.

deposition in a marine environment. These breccias and conglomerates are interpreted as mass gravity flow deposits primarily deposited on fan deltas, partly subaerially, partly submarine.

AUERNIG GROUP

The Bombaso Formation is overlain by the Auernig Group, which is up to 1.200 m thick and composed of Meledis-, Pizzul-, Corona-, Auernig- and Carnizza Formations according to Selli (1963) (Fig. 2). The succession consists of cyclic clastic and carbonate rocks of a shallow marine environment. Meledis-, Corona- and Carnizza Formations predominantly consist of clastic sediments, Pizzul- and Auernig Formations contain substantial quantities of fossiliferous carbonate rocks. The main lithofacies types are a quartz-rich conglomerate of a nearshore environment, frequently overlain by shale containing abundant and well-preserved megaplant fossils, trough-crossbedded and hummocky crossbedded sandstone (shoreface), bioturbated and locally fossiliferous siltstones and shales (offshore) and fossiliferous limestones containing calcareous algae (*Anthracoporella spectabilis, Archaeolithophyllum missouriense, Epimastopora, Eugonophyllum*), fusulinids, small foraminifers, echinoderms, bryozoans, *Tubiphytes*, sphinctozoans, solitary corals and others. Massive limestones represent algal mounds (*Anthracoporella* mounds; Krainer 1995), in the Meledis Formation small mounds formed of auloporid corals are present (Flügel & Krainer 1992). In the upper part of the Auernig Group (Corona-, Auernig- and Carnizza Formations) these lithofacies types form prominent clastic-carbonate regressive-transgressive cycles ("Auernig cyclothemes") with thicknesses of 10-40 m (Fig. 3). Within these cycles conglomerates formed during relative sea-level lowstands and fossiliferous limestone was deposited during periods of relative sea-level highstands. The formation of these cycles is related to eustatic sea-level changes caused by Gondwanan glaciation (Massari & Venturini 1990; Krainer 1992, 1995).

RATTENDORF GROUP

The Rattendorf Group comprises a succession of shallow marine sediments of nearshore, inner shelf and outer shelf environments. The succession is divided into Lower Pseudoschwagerina Limestone (LPL), Grenzland Formation and Upper Pseudoschwagerina Limestone (UPL) (Fig. 2).

The LPL is composed of three depositional cycles consisting of shallow marine limestones and thin intervals of clastic sediments (Fig. 4). Clastic intervals form the base of the depositional succession and were deposited during relative sea-level lowstands. During transgression well bedded fossiliferous limestones and massive algal mounds accumulated. Bedded cherty limestones with marl intercalations are interpreted to have been deposited during relative sea-level highstands with water depths of some tens of meters. Fusulinid-rich limestone beds are present in different stratigraphic levels, particularly at the base and on top of the clastic intervals. Fusulinids of these beds are considered as parautochthonous assemblages, accumulated during periods of low

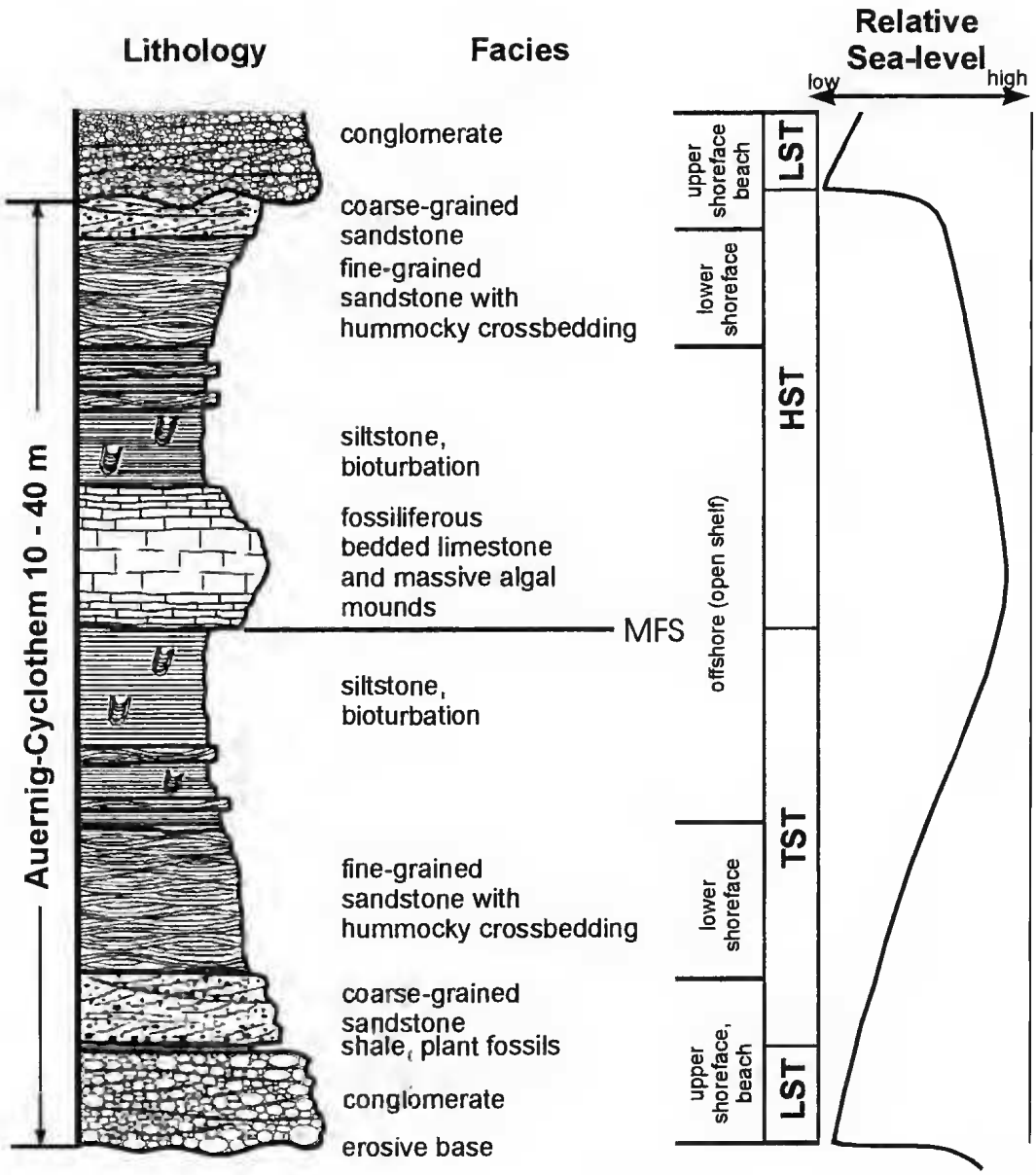


FIG. 3. — Idealised "Auernig-Cyclothem" from the upper part of the Auernig Group in the Garnitzenberg-Kronalpe area, Carnic Alps.

sediment input (see Homann 1969; Flügel 1974, 1977; Buggisch *et al.* 1976; Forke *et al.* in press). The Grenzland Formation is a cyclic succession, predominantly composed of shallow marine clastic sediments (quartz-rich conglomerate, sandstone and siltstone) and intercalated thin fossiliferous carbonate intervals (Buttersack & Boeckelmann 1984; Boeckelmann 1985). A caliche unit and a red shale unit with scattered angular quartz grains in the upper part of the succession indicate subaerial exposure. Fusulinids were described from the thin carbonate intercalations (Kahler & Kahler 1937; Kahler 1985; Forke 1995). Plant fossils have been described

from a thin shale intercalation by Fritz & Boersma (1984).

The Upper Pseudoschwagerina Limestone is represented by a cyclic succession composed predominantly of dark-grey, thin bedded fossiliferous limestones and intercalated thin intervals of silt- and sandstones and fine-grained, well-rounded and well-sorted quartz rich conglomerates. Limestones contain abundant fossils, particularly calcareous algae (Homann 1972), small foraminifers (Flügel 1971), fusulinids, corals, bryozoans, brachiopods, gastropods, pelecypods and echinoderm fragments. Microfacies has been described by Flügel (1968) and Buttersack & Boeckelmann (1984). Cycles indicate repeated shifting from nearshore to offshore environments in an open marine shelf-lagoon with normal water circulation (Flügel 1981). Compared to the LPL and Grenzland Formation the limestones are characterized by more diverse biota and microfacies types (Flügel 1971, 1981; Flügel *et al.* 1971).

Trogkofel Group

The Trogkofel Group is composed of approximately 400 m thick, predominantly massive, subordinately bedded limestones (Trogkofel limestone, Tressdorf limestone and Goggau limestone). The limestones were deposited in shallow, restricted and open marine shelf-lagoons with only minor bathymetrical differences. *Tubiphytes/ Archaeolithoporella* build-ups composed of sediment-binding organisms like encrusting foraminifers, phylloid algae, *Tubiphytes, Archaeolithoporella* and bryozoans formed at the shelf edge (Flügel 1980a, b, 1981). Flügel & Flügel-Kahler (1980) described 46 species of calcareous algae, the fusulinid fauna is represented by 70 species (Kahler & Kahler 1980).

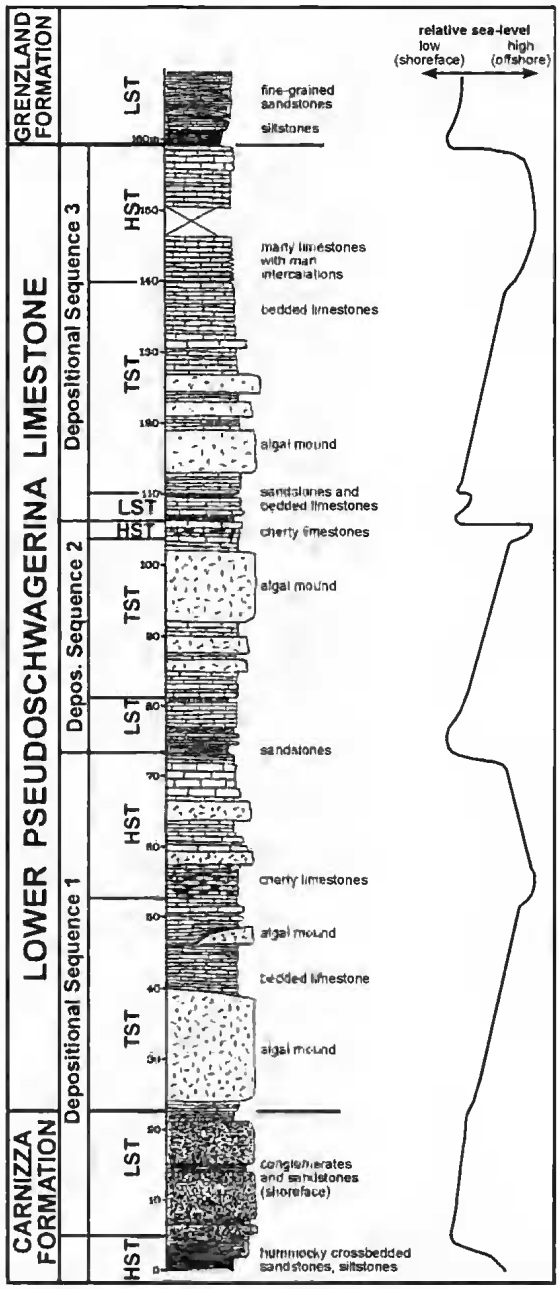


Fig. 4. — Stratigraphic column of the Lower Pseudoschwagerina Limestone (Rattendorf Group) from the north-western side of the Schulterkofel (type section).

BIOSTRATIGRAPHY

Fusulinids

The first comprehensive paper on fusulinids from Late Paleozoic limestones of the Carnic Alps was presented by Schellwien (1898). From 1932-1996 F. Kahler (till 1982 with his wife G. Kahler) intensively studied the fusulinid faunas of the Bombaso Formation, Auernig, Rattendorf and Trogkofel Groups. The biostratigraphic classification and subdivision of the Late

Paleozoic sequence of the Carnic Alps is mainly based on the detailed investigation of fusulinids by F. Kahler & G. Kahler. Their data are published in numerous papers, summaries are given in Kahler (1983, 1985, 1986, 1989). Additional data concerning fusulinid stratigraphy have been contributed by Pasini (1965, 1990) and recently by Forke (1995), Forke *et al.* (in press) and Davydov (Davydov & Krainer, in press). We use the sign * in cases of difference from original authors taxonomy.

Bombaso Formation and Meledis Formation

The oldest fusulinid fauna of the Carnic Alps is described from carbonate rocks on top of the Bombaso Formation west of Zollnersee, consisting of *Ozawainella angulata, O. kumpani* and *O.* cf. *mosquensis, Fusulinella colaniae rasdorica, F. fluxa, Beedeina* nytvica callosa, Fusulina* (s.str.) *fortissima, Quasifusulinoides* mjachkovensis, Quasifusulinoides* quasifusulinoides* and *Quasifusulinoides juvenatus* (Kahler 1983). According to Kahler (1983), this fusulinid fauna corresponds to the *Fusulinella bocki* zone of the Late Myachkovian of the Russian classification.

Carbonate from the lowermost Meledis Formation of the Auernig Group yielded a *Fusulinella, Fusulina* and *Quasifusulinoides* fauna near Waidegger Alm indicating lowermost Kasimovian C_3A_1 (Kahler 1986) and a *Protriticites*-fauna containing *P. pseudomontiparus* SW of Zollnersee pointing to lowermost Kasimovian A_1 (Kahler 1983).

Recent investigation yielded a small fusulinid assemblage from conglomerates of the Bombaso Formation near Straniger Alpe, composed of *Quasifusulinoides quasifusulinoides, Q. fallax, Q. intermedia, Protriticites ovatus, P.* cf. *ovoides.* The composition of this assemblage is most similar to that from the *Protriticites ovatus - Praeobsoletes burkemensis* zone in the stratotype section in the Moscow Basin and occurs only in the Peskovskaya Formation of the Myachkovian Horizon of the Moscovian (Davydov 1997; Davydov & Krainer, in press). A similar assemblage was found near the top of the Bombaso Formation west of Zollnersee and includes *Fusiella lancetiformis, Beedyina consobrina, B. peskensis, B. pseudocylindrica, Fusulinella rara, Quasifusulinoides pakhrensis, Q. pulchella, Protriticites ovatus.*

Carbonates from the basal Meledis Formation near Zollnersee and at Cima Val di Puartis contain fusulinids of the *Protriticites pseudomontiparus* zone in its lowermost part, and of the *Montiparus paramontiparus* zone in the middle portion of this formation. The *Protriticites pseudomontiparus* zone is characterized by *Protriticites globulus, Pr. pseudomontiparus, Pr. sphaericus, Pr. rotundatus, Pr. ovoides, Pr. lamellosus* and *Praeobsoletes burkemensis.* These species are characteristic only in the *Protriticites pseudomontiparus - Obsoletes obsoletus* zone of the Russian Platform (Kreviakian Horizon) and Timan-Pechora region, in the Urals, Donets Basin, Central Asia, Spitsbergen and in the Cantabrian Mountains (see Davydov & Krainer, in press).

The *Montiparus paramontiparus* subzone is characterized by the occurrence of *Praeobsoletes pauper, P. burkemensis, Obsoletes timanicus, O. obsoletus, Montiparus paramontiparus, M. umbonoplicatus, M. montiparus, M. likharevi, M. rhombiformis* and *M. priscus. Montiparus* species found in the Carnic Alps are well-known from middle Kasimovian strata of the Russian Platform (Khamovnicheskian), Timan-Pechora Basin, the Urals (upper part of the Orlovskyi Horizon), Central Asia, Spitsbergen and the Cantabrian Mountains. In Central Asia and the Southern Urals the *Montiparus montiparus* zone is divided into two subzones: the *M. paramontiparus* subzone in the lower part and the *M. subcrassulus* subzone in the upper part. The assemblage recognized in the Carnic Alps corresponds to the *M. paramontiparus* subzone (see discussion by Davydov & Krainer).

It should be indicated that the representatives of the *Praeobsoletes-Obsoletes* lineage in the Carnic Alps appear later. In the Russian Platform, the Urals, Donets Basin and Central Asia *Praeobsoletes* first appears in the uppermost Myachkovian and ranges into the lowermost Kasimovian. *Obsoletes* first appears at the base of the Kasimovian and is most characteristic for the Early Kasimovian (Kreviakian). Only rarely *Obsoletes* ranges into the middle Kasimovian (Khamovnicheskian). In the Carnic Alps, similarly with the Cantabrian Mountains and

Spitsbergen (Villa *et al.* 1992; Nilsson & Davydov 1993), the representatives of the *Praeobsoletes-Obsoletes* lineage are rare. *Praeobsoletes* first appears only in the lowermost Kasimovian (Kreviakian) and *Obsoletes* first appears in the uppermost Kreviakian or only in the Khamovnicheskian.

In the very top of the Meledis Formation in the RC section (RC-12b and RC-13) the following fusulinids were identified: *Ferganites ferganensis* Miklukha-Maclay, *Rauserites* sp., and *Rauserites rossicus* (Schellwien) (Fig. 5A-E). The last species in the Russian Platform and the Urals characterise lowermost Gzhelian or Rechitskyi Horizon of the Russian Platform (Rosovskaya 1958; Makhlina *et al.* 1984; Davydov & Popov 1986). *Ferganites ferganensis* in Central Asia as well as in S. Urals characterises also early Gzhelian, an equivalent of Amerevskyi Horizon of the Russian Platform (Fig. 6) (Davydov & Popov 1986; Popov *et al.* 1989). We suggest that the very upper portion of the Meledis Formation is early Gzhelian in age (Fig. 6).

Pizzul Formation, Corona Formation, Auernig Formation and Carnizza Formation

According to Kahler (1985) the Pizzul Formation (Untere kalkreiche Schichtgruppe) is characterized by the occurrence of the following fusulinid species: *Triticites oryziformis, Rauserites* noinskyi plicatus; Daixina alpina vetusta, D. sokensis* (s.str.*), *D. naviculaeformis, D. sakmarensis* and *Quasifusulina eleganta*. Recent studies of non-oriented thin-sections from the Pizzul Formation show dominance of a *Schagonella* and *Daixina* fauna. Because in Central Asia and southern Urals representatives of the *Daixina sokensis* group appear earlier than in the Russian Platform, and because of the stratigraphic position of the Pizzul Formation above the early Gzhelian and below the Orenburgian, we believe that the Pizzul Formation has to be an equivalent of the late Gzhelian (*s.str.*).

From a thin carbonate bed of the Corona Formation at Garnitzenberg (Mittlere kalkarme Schichtgruppe) Kahler (1983) reported *"Pseudofusulina multiseptata", Daixina alpina, D.* ex gr. *admirabilis* and *Schagonella* spp. also were recently identified by Davydov. The species *Pseudofusulina multisepta* originated from the Carnic Alps (Schellwien 1898), but for more then sixty years was used in the literature as a Late Permian *Parafusulina* species, reported from many Tethyan regions. Until revision and solving of this taxonomical problems we use inverted commas for this species.

In Darvas and in S. Urals *Schagonella* in general dominated in the middle Gzhelian. *Daixina admirabilis* originally was described from the Orenburgian of the Urals (Zolotova *et al.* 1978), but also was reported from the late Gzhelian (*s.str.*) of Darvas (Davydov 1986). Fusulinid data from Pizzul and Corona Formations do not constrain a specific age. Based on the stratigraphic position of Pizzul and Corona Formations above an equivalent of the early Gzhelian (Upper Meledis) and below the Orenburgian Auernig Formation, the age of both formations can be estimated as late Gzhelian (*s.str.*) (Amerevskyi and Pavlovoposadskyi Horizons of Russian Platform).

The Auernig Formation (Obere kalkreiche Schichtgruppe) of Garnitzenberg and Kronalpe contains *Boultonia europaea; Triticites schwageriniformis, T. perstabilis; Daixina* alpina, D.* communis, D.* alpina fragilis, D.* devexa acallosa; "Pseudofusulina multiseptata", "P. paraconcinna"; Dutkevitchia dastarensis, D."kargalensis", D."ruzhencevi"; Quasifusulina tenuissima, Q. compacta, Q. karawankensis, Q. kaspiensis, Q. phaselus, Q. pseudoelongata, Q. pseudolonga* (Kahler 1983, 1985).

The Carnizza Formation (Obere kalkarme Schichtgruppe) of Garnitzenberg contains *Daixina alpina antiqua = alpina* and the subspecies *fragilis*, and *Dutkevitchia dastarensis.*

According to Kahler (1986, 1989) Pizzul Formation, Corona Formation, Auernig Formation and Carnizza Formation are of Gzhelian age (Gzhelian E).

Recent studies in the southern Urals, Donets Basin and in Central Asia (Darvas and southern Fergana) showed that *Boultonia europaea* and *Dutkevitchia dastarensis* first appear at the basal Orenburgian *Daixina sokensis* zone (Davydov 1984, 1992; Popov *et al.* 1989; Davydov *et al.* 1993). *Dutkevitchia ruzhenzevi* and *Dutkevitchia kargalensis* everywhere first appear only in the

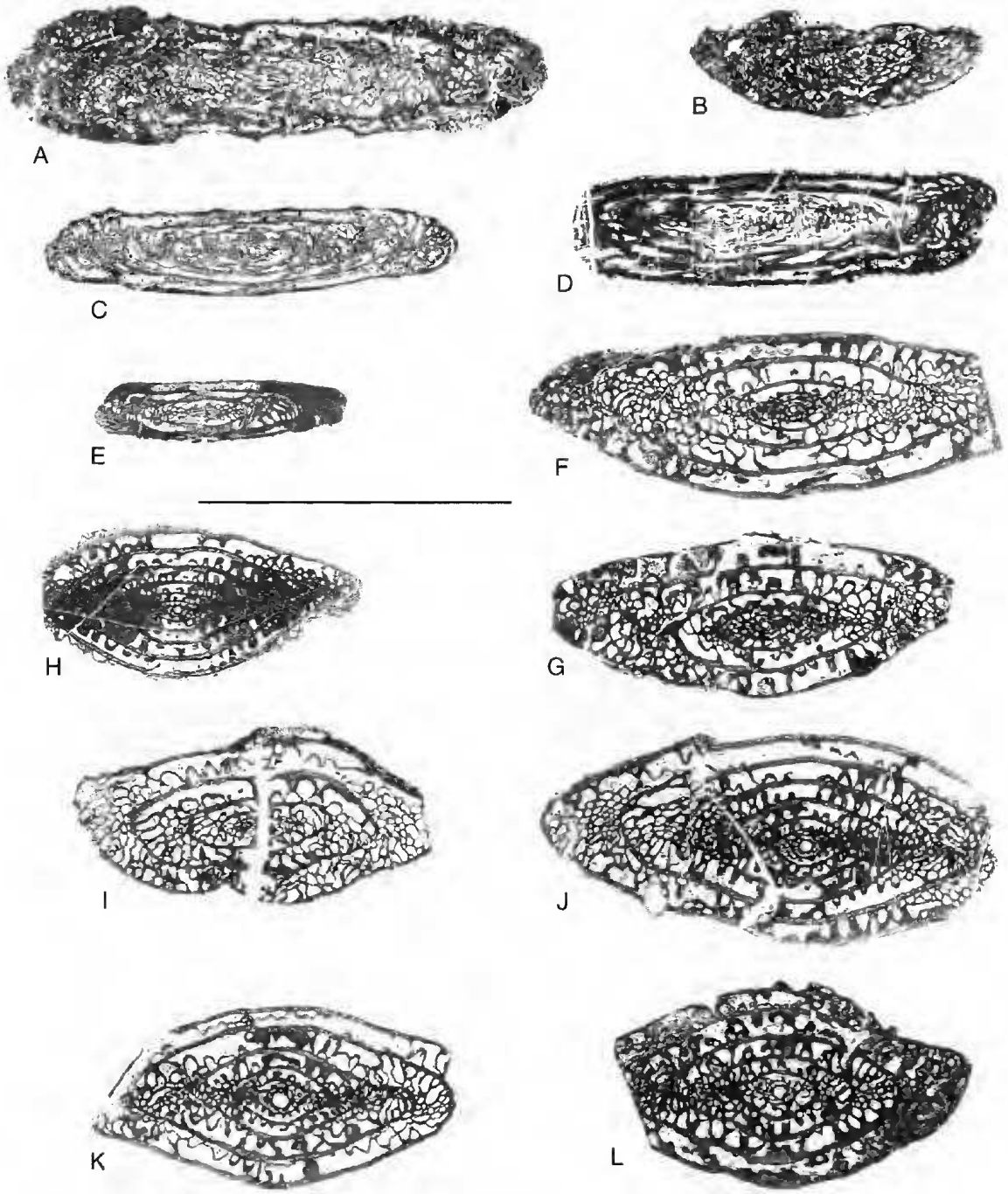


FIG. 5. — Stratigraphically significant fusulinids from the Meledis Formation (basal Auernig Group) and Lower Pseudoschwagerina Limestone (Rattendorf Group). **A**, *Rauserites rossicus* (Schellwien, 1908), tangential section, RC-13-4. **B**, *Rauserites* sp., oblique section, RC-13-4. **C-E**, *Ferganites* aff. *ierganensis* (Miklukho-Maclay, 1948): **C**, axial section, RC-12b-9; **D**, tangential section, RC-12b-12; **E**, paraxial section, RC-12b-2. **F**, **G**, *Schellwienia bornemani* (Leven *et* Scherbovich, 1978): **F**, axial section of typical specimen, SK-157-4; **G**, axial section of short specimen, SK-157-2. **H**, *Zigarella panjiensis* (Leven *et* Scherbovich, 1978), axial section of typical specimen, SK-157-5. **I**, *Likharevites inglorius* (Bensh, 1962), axial section, SK-157-1. **J-L**, *Schellwienia bornemani* (Leven *et* Scherbovich, 1978): **J**, axial section of specimen with small axial fillings, SK-157-12; **K**, axial section of typical specimen, SK-157-13; **L**, axial section of short specimen, SK-157-9. Scale bar: 0,5 cm.

early Asselian, and we believe that their occurrence in the Orenburgian Auernig Formation is misidentified. Therefore we place inverted commas with both of these species. The age of Auernig and Carnizza Formations for now can be estimated as Orenburgian (equivalent of Nogonskian of Russian Platform) (Fig. 6).

Lower Pseudoschwagerina Limestone (Schulterkofel Formation)

From the uppermost part of the Lower Pseudoschwagerina Limestone near Rudnigalm Kahler (1985) described the following fusulinid species: *Boultonia europaea*; *Rugosofusulina arianica*, *R. directa*, *R. latioralis*, *R.* cf. *pandae*, *R. praevia egregia*, *R. stabilis*, *R. stabilis longa*; *Paraschwagerina* cf. *tinvenkiangi elongata*, *Occidentoschwagerina alpina* and *"Eozellia miharanoensis" (= Ultradaixina* ex gr. *postgallowayi)*. From Schulterkofel Kahler (1983) listed *Boultonia europaea*; *Ruzhenzevites* parasolidus*; *Rugosofusulina* cf. *pandae*, *R. serrata*, *R. likana*, *R. praevia* and *Rugosochusenella* pseudogregaria*.

In a recent paper Kahler & Krainer (1993) described a fusulinid fauna composed of about 30 species from the upper part of the LPL of the Schulterkofel section. Species of *Triticites* and *Rugosofusulina* dominate, whereas those of rare *"Daixina"* (=*Schellwienia*), *Rugosochusenella* and *Ruzhenzevites* occur. The Carboniferous/Permian boundary was drawn at the first appearance of *"Pseudoschwagerina"* and *"Occidentoschwagerina alpina"* (= *Ultradaixina*) in the upper part of the section. From our point of view, specimens named as *Pseudoschwagerina* could not be identified even with genus name, because in the tangential sections reported, the juvenarium structure, which is most important for taxonomy, is not present.

According to Forke *et al.* (in press) the lower part (depositional Sequence 1) of the LPL in the Schulterkofel section, characterized by the occurrence of *Ruzhenzevites ferganensis* and *Ruzhenzevites parasolidus* without species of the genus *Ultradaixina*, is correlated with the *Sokensis* zone. The overlying part (uppermost part of depositional Sequence 1 up to the top of depositional Sequence 3) corresponds to the *Bosbytauensis-Robusta* zone. The C/P-boundary of Forke *et al.* lies near the base of the overlying Grenzland Formarion.

The following species were identified in recent studies of LPL in the Schulterkofel section: in the very lower portion of LPL (TST of Sequence 1) we found *Daixina sokensis*, *Schellwienia oblonga* and *Dutkevitchia bimorpha*. In the HST of Sequence 1 *Ultradaixina postsokensis* and *Schellwienia ulukensis* and within Sequence 2, *Schellwienia ulukensis* and *Zigarella elegans* were identified. Most interesting data were retrieved from the top of Sequence 3, where *Schwagerina versabile*, *Schellwienia hornemani*, *Zigarella panjiensis* and *Likharevites inglorius* were identified (Fig. 5 F-L).

To estimate the age of the LPL Formation we can indicate the following: in Southern Fergana and Darvas *Ruzhenzevites ferganensis* first appears in the middle portion of an equivalent of the *Daixina sokensis* zone (Davydov 1984; Popov *et al.* 1989). *Ruzhenzevites parasolidus* is a more advanced species and in Darvas it first appears in the very top of the *Daixina sokensis* zone and ranges higher. In Southern and Northern Fergana this species occurs in the *Schwagerina robusta-Ultradaixina bosbytauensis* zone and ranges higher into the Asselian. *Schellwienia ulukensis* in Central Asia as well as in the Southern Urals section occurs only in the *Schwagerina robusta-Ultradaixina bosbytauensis* zone. *Schwagerina versabile* in Darvas and in the Southern Urals appears in the very top of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone, but is characteristic of the early Asselian. *Schellwienia hornemani*, *Zigarella panjiensis* and *Likharevites inglorius* in Central Asia and the Southern Urals are known only from the Asselian (Bensh 1962 ; Leven & Scherbovich 1978; Davydov 1984; Popov *et al.* 1989) (see correlation chart, Fig. 6).

Based on all this data we can suggest the following. The TST (transgressive systems tract; Fig. 4) of Sequence 1 of LPL can be correlated with the uppermost part of the *Daixina sokensis* zone. The HST (highstand systems tract) of Sequence 1 can be correlated with the lower portion of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone or with the *Ultradaixina postsokensis* zone of the Southern Urals and

Darvas. Most part of Sequence 2 (except the HST) conventionally can be correlated with the middle portion of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone or with the *Ultradaixina bosbytauensis* zone of the Southern Urals and Darvas. The HST of Sequence 2 and LST (lowstand systems tract) and TST of Sequence 3 should be correlated with the upper portion of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone or with the *Ultradaixina postgallowayi* zone of the Southern Urals and Darvas. The HST of Sequence 3 very probably is Early Asselian in age. The last conclusion is based on the following: in Darvas, the Southern Urals and in the Donets Basin the acme-zone (maximum of occurrences) for *Ultradaixina* is in the upper portion (but not uppermost) of the *Schwagerina robusta-Ultradaixina bosbytauensis* zone. In the very upper portion of this zone *Ultradaixina* is rare and perhaps extinct, and absolutely absent in the Asselian. Similarly in the Schulterkofel section the acme-zone for the *Ultradaixina* is the HST of Sequence 2 and the LST of Sequence 3. In the TST of Sequence 3 *Ultradaixina* is extremely rare and absolutely no *Ultradaixina* is present in the HST of Sequence 3. *Schellwienia bornemani* and *Zigarella panjiensis* originally were described from the middle Asselian of Darvas. In the Southern Urals they occur in the early-middle Asselian. *Likharevites inglorius* in Darvas, Northern Fergana, the Southern Urals and Predonets Trough was found in the early-middle Asselian (Bensh 1962; Leven & Scherbovich 1978; Davydov 1990; Davydov *et al.* 1993). So, occurrences of *Schellwienia bornemani*, *Zigarella panjiensis* and *Likharevites inglorius* suggest Asselian age for the HST of Sequence 3 of the Lower Pseudoschwagerina Limestone.

Grenzland Formation

From limestones of the Grenzland Formation at Rudnigsattel Kahlet (1985) reported the occurrence of *Quasifusulina* cf. *compacta*, *Q. eleganta*, *Q. kaspiensis*, *"Darvasites contractus"*, *Zigarella pseudopointeli*, *Sphaeroschwagerina carniolica*, *Pseudoschwagerina extensa* and *Sphaeroschwagerina sphaerica*.

From the type section near Rattendorfer Alm, Kahler & Kahler (1937) described *Pseudoschwagerina aequalis*, *Ps. extensa* and *Sphaeroschwagerina* confinii*, from the eastern side of Schulterkofel, *Pseudoschwagerina turbida* and *Sphaeroschwagerina* carniolica*.

Based on the occurrence of *Pseudoschwagerina aequalis*, *Sphaeroschwagerina* confinii* and *Sphaeroschwagerina* carniolica* Kahler (1986) dated the Grenzland Formation as middle Asselian.

Forke (1995) described *Sphaeroschwagerina glomerosa* from the Grenzland Formation near Rudnigsattel.

Most of the species of Grenzland Formation, except *Quasifusulina* species, are known from the middle as well as from the late Asselian. *Sphaeroschwagerina glomerosa* indicates only late Asselian age. Base on this we can suggest middle-late Asselian age for the Grenzland Formation (see Fig. 6).

Upper Pseudoschwagerina Limestone

From the type section of the Upper Pseudoschwagerina Limestone at Zottachkopf Kahler described the following fusulinid species: *Boultonia willsi*, *Pseudofusulina regularis*, *McCloudia* haydeni*, *Darvasites contractus*, *Schwagerina "krtowi"*, *Pseudoschwagerina pulchra*, *Biwaella inopinata* and *Rugosochusenella paragregaria*.

Red limestones at Trogköhe and at point 2016 (according to Kahler belonging to the Trogkofel Limestone, after Forke to the Upper Pseudoschwagerina Limestone) contain a rich fusulinid fauna. Kahler (1983, 1985) reported the following species: *Boultonia willsi*, *Quasifusulina uimia*, *Q. pseudoelongata*, *Q. tenuissima*, *Q.* cf. *kaspiensis*, *"Chusenella cheni"*, *"Ch. chihsiaensis"*, *"Ch. rabatei"*, *Schwagerina* moelleri*, *Schw.* paraconfusa*, *Eoparafusulina* "tschernyschewi"*, *Robustoschwagerina geyeri*, *R. schellwieni*, *Paraschwagerina inflata longa*, *Sphaeroschwagerina* carniolica*, *S.* lata*, *S.* pulchra*, *Zellia heritschi*, *Z. galatea*.

According to Forke (1995) the red limestones contain the following stratigraphically important species: *Zellia heritschi*, *Robustoschwagerina schellwieni*, *R. geyeri*, *Paraschwagerina inflata*, *Schwagerina moelleri*, *Schwagerina* cf. *verneuili*

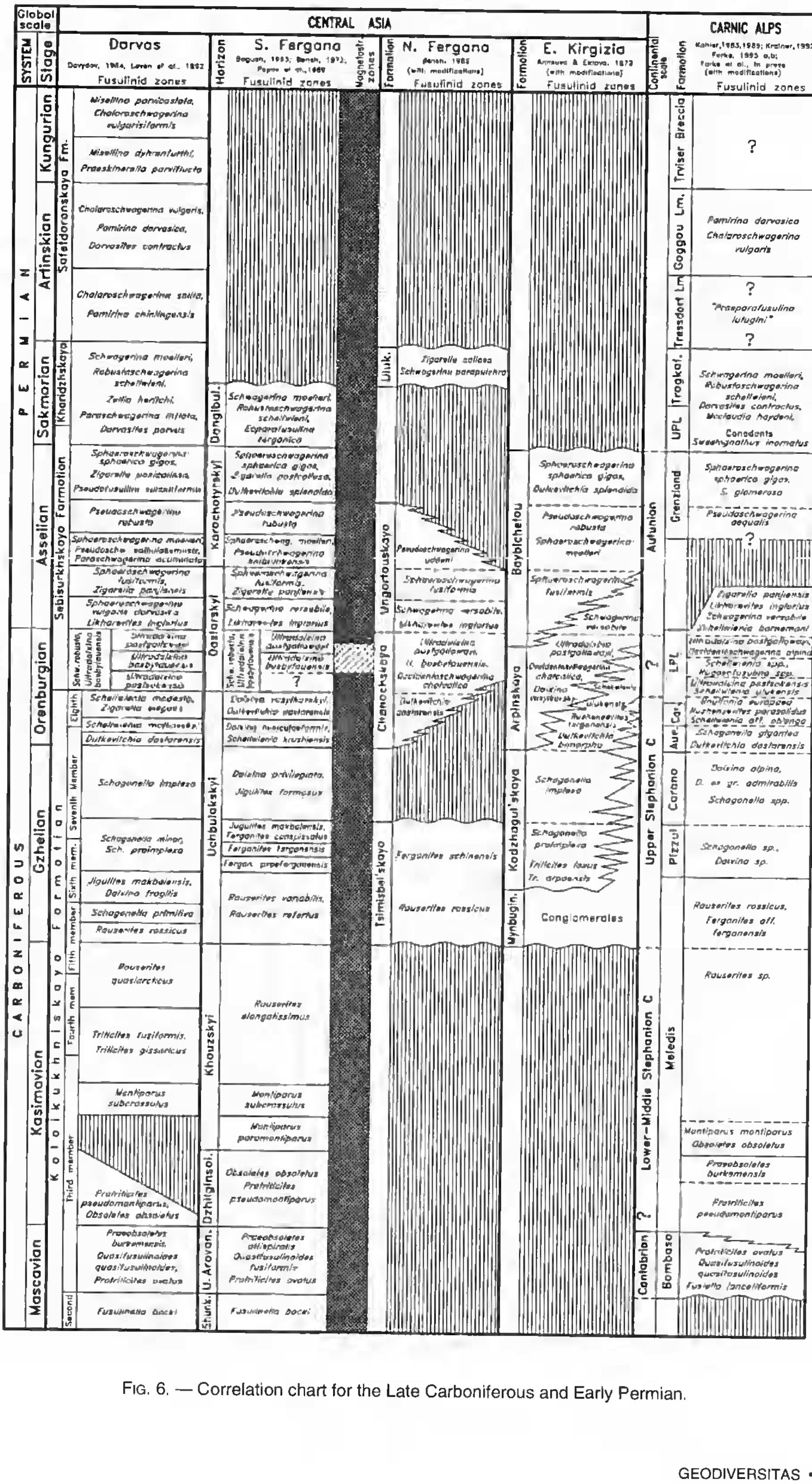
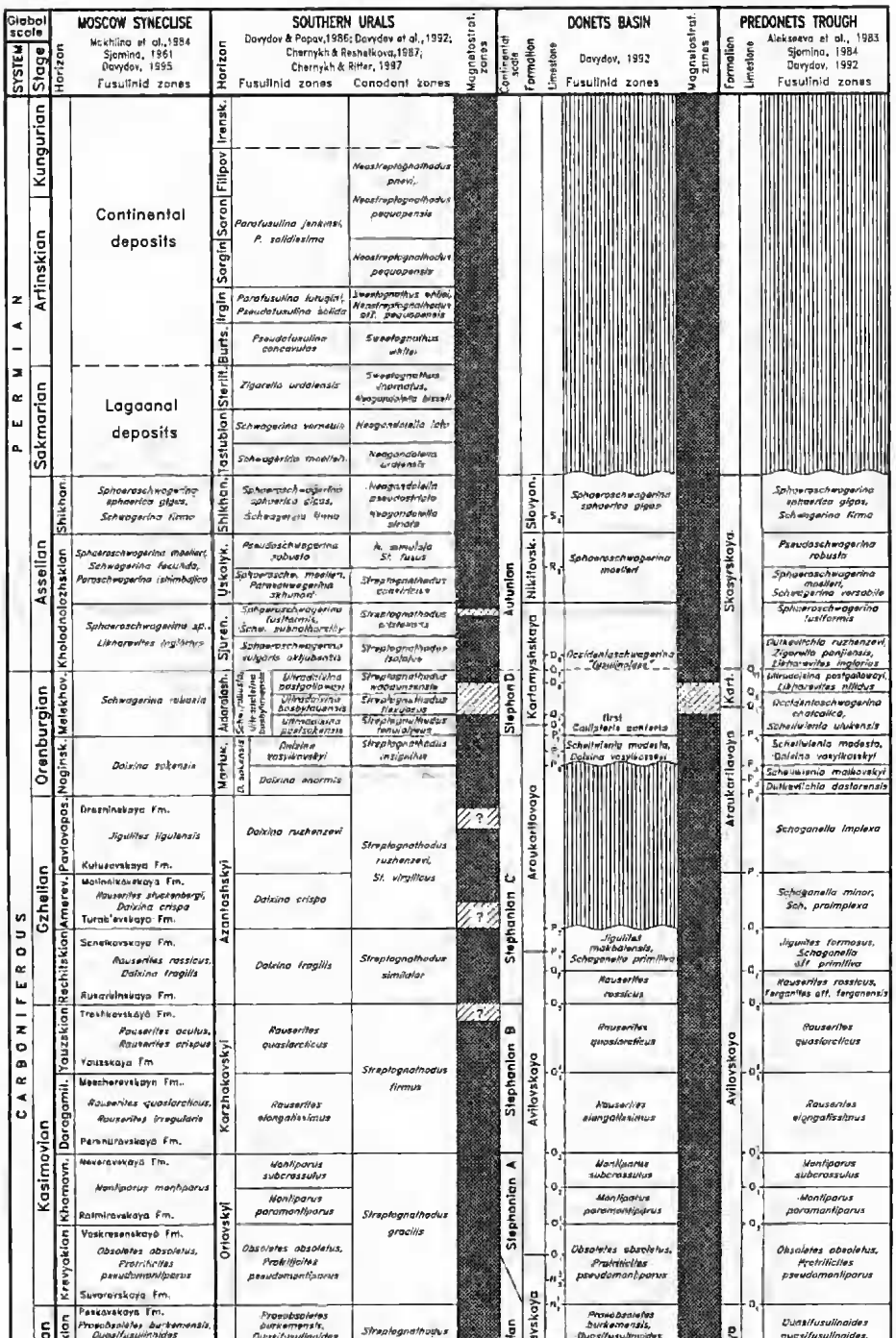


FIG. 6. — Correlation chart for the Late Carboniferous and Early Permian.


Global scale
SYSTEM
Stage
Horizon
MOSCOW SYNECLISE
Fusulinid zones
SOUTHERN URALS
Fusulinid zones
Conodont zones
Magnetostrat. zones
Continental facies
Formation
Limestone
DONETS BASIN
Fusulinid zones
PREDONETS TROUGH
Fusulinid zones
PERMIAN
CARBONIFEROUS
Kungurian
Artinskian
Sakmarian
Asselian
Orenburgian
Gzhelian
Kasimovian
Moscovian
Continental deposits
Lagoonal deposits
Autunian
Stephanian C
Stephanian B
Stephanian A
Cantabrian
Skasyrskaya
Artinskaya
Sterlitamakian
Baskirian
Aleksandrovskaya
Avilovskaya
Isaevskaya

and *Pseudofusulinoides pusillus*. Forke (1995) dates the Upper Pseudoschwagerina Limestone as Sakmarian (*Robustoschwagerina geyeri* zone and *Zellia heritschi* zone).

Trogkofel Group

After Kahler & Kahler (1980) the fusulinid fauna of the Trogkofel Group consists mainly of species of the genera *Triticites*, *Darvasites*, *Pseudofusulinoides*, *Pseudofusulina*, "*Praeparafusulina*", *Pamirina* and *Minojapanella*. They described about seventy species. Stratigraphically important index fossils are *Schwagerina* moelleri*, characteristic for the lower part (Trogkofel limestone), "*Parafusulina lutugini*" typical for the Tressdorf limestone, and the *Chalaroschwagerina* vulgaris*-group together with *Pamirina darvasica* in the Goggau limestone. True parafusulinids and *Misellina* species are lacking.

Kahler (1986) dated the Trogkofel limestone as Sakmarian (Tastubian-Sterlitamakian) due to the occurrence of *Robustoschwagerina schellwieni* and *Pseudoschwagerina lata*. The Tressdorf limestone, containing *"Praeparafusulina lutugini"* is classified as Early Artinskian (Burchev), and the Goggau limestone, which contains *Chalaroschwagerina* vulgaris* and *Pamirina*, is dated as Late Artinskian (Irgin). According to Forke (1995) the Trogkofel limestone is Late Sakmarian to Early Artinskian in age.

It should be noted, that Sakmarian and Artinskian fusulinids of the Urals can not occur in the Tethyan section, as the Carnic Alps, because beginning in the early Sakmarian the Boreal province was completely isolated from the Tethyan provinces. None Artinskian fusulinid species of the Urals are known from Tethys sediments, but those listed, we believe, are identified erroneously. For this reason *"Praeparafusulina lutugini"* takes inverted commas and indicates taxonomical misidentification.

We cannot estimate the age of the Trogkofel limestone based only on fusulinids for now. It could be Sakmarian as well as early Artinskian. Because the Goggau Limestone contains *Chalaroschwagerina vulgaris* and *Pamirina darvasica*, which in Darvas characterises the late Yakhtashian (Early Artinskian) (Leven *et al.* 1992), we can conventionally estimate the age of the Tressdorf limestone as early Artinskian (Fig. 6).

The following problems for fusulinid biostratigraphy should be addressed immediately:
– precise fusulinid biostratigraphy of Pizzul, Corona, Auernig and Carnizza Formations;
– complete characteristic of C/P boundary beds and better criteria for the C/P boundary position;
– age of Grenzland Formation;
– fusulinid biostratigraphy and succession of the Trogkofel Limestone;
– restudy of the Tressdorf and Goggau Limestones.

CONODONTS

The occurrence of conodonts in Late Paleozoic carbonates of the Carnic Alps was first noted by Flügel *et al.* (1971) from the Rattendorf Group and Boeckelmann (1983) from the Auernig Group (discoveries of individual conodont fragments, which have no stratigraphic importance).

Forke (1995) described a conodont fauna from red limestones of the Upper Pseudoschwagerina Limestone. The conodont fauna is composed of the following species: *Aethotaxis advena*, *Hindeodus minutus*, *Mesogondolella* cf. *bisselli*, *Diplognathodus expansus*?, *Sweetognathus inornatus* and *Sweetognathus* aff. *whitei*.

In central and western USA *S. inornatus* and *S.* aff *whitei* appear in the Late Wolfcampian. *S. inornatus* belongs to the *Sweetognathus whitei-Mesogondolella bisselli* zone. In the Urals, *Sweetognathus inornatus* appears in the Sterlitamakian (Late Sakmarian) and ranges into the Artinskian. *Sweetognathus whitei* is known only in Aktastian (Early Artinskian) (Chernykh & Reshetkova 1987; Chernykh & Chuvashov 1993). *Sweetognathus whitei* in the Trogkofel Group is represented by incomplete atypical specimens (identified with "affinity" sign). The appearance of *Sweetognathus inornatus* and *S.* aff. *whitei* together with *Robustoschwagerina* and *Zellia*, but without typical Artinskian fusulinid faunas (*Pamirina, Chalaroschwagerina*) in the Carnic Alps, indicates at this time Sakmarian age.

According to Forke (1995) the Upper Pseudoschwagerina Limestone is of Sakmarian age

(based on the occurrence of *Robustoschwagerina geyeri* and *Zellia heritschi*). Forke (1995) in his paper presenrs correlation charts of the Rattendorf and Trogkofel Group with sections from the Urals, Darvas, N-China, S-China, Japan and USA.

Fossil flora

Plant fossils were reported from the Bombaso Formation and Auernig Group more than 100 years ago. Höfer seems to be the first who collected plant fossils in 1869 in the Monte Corona/Kronalpe and Casera For/Ofenalm area. The specimens were determined and described by Unger (1869), the taphoflora list contains 19 taxa.

The determinations of Unger (1869) were later revised by Reichardt (1937) and Fritz & Boersma (1982).

Taphoflora lists from the Monte Corona section (Corona Formation) have been published by Stache (1874), Schellwien (1892), Frech (1894) and Geyer (1897).

From the localities Cason di Lanza (?Meledis Formation) and Monte Pizzul (type locality for the Pizzul Formation) plant fossils were described by Tommasi (1889), Bozzi (1890) and Vinassa De Regny & Gortani (1905).

Later, numerous new localities of plant fossils within the Auernig Group were discovered by Kahler, Metz and others in the Auernig, Nassfeld and Schulterkofel areas. The plant fossils were described by Reichardt (1933) and Kielhauser (1937), a first summary on the fossil flora of the Auernig Group including 25 taxa was given by Reichardt (1937) and Jongmans (1938).

Jongmans (1938) classified the flora of the Auernig Group as Westphalian D (= Early Stephanian) and Westphalian E (= Late Srephanian). He also pointed out that within the Auernig Group the Schulterkofel flora represents the youngest flora.

Berger (1960) reported 30 taxa from new localities, most of them within the Bombaso Formation and lowermost part of the Auernig Group. He classified the fossil flora as Westphalian D. Plant fossils have also been described from several new intervals within the uppermost Corona-, Auernig- and Carnizza Formations. (Kahler *et al.* 1933; Kahler & Prey 1963; Fenninger & Schönlaub 1972; Francavilla 1974).

Fritz & Boersma (since 1980) and Fritz & Krainer (since 1993) systematically investigated the fossil flora of the Bombaso Formation and Auernig Group from more than 30 localities. Plant fossils are found in all formations of the Auernig Group, from most localities the stratigraphic position within the section is exactly known.

From all localities 105 taxa are described (Equisetophyra 26 taxa, Lycophyta 12 taxa, Filicophyta, Pteridospermae and Pteridophylla 57 taxa, Cordaitospermae 9 taxa; Coniferae 1 taxon, see Fritz *et al.* 1990; Fritz & Krainer 1993, 1994, 1995).

From the Grenzland Formation the occurrence of plant fossils (no determinations) has been noted by several authors (Felser *et al.* 1956; Felser & Kahler 1963; Kahler & Prey 1963; Flügel 1974). Herzog (1984) discovered a plant fossil bearing interval and collected a flora which was determined and described by Fritz & Boersma (1984) and Fritz *et al.* (1990). So far known this locality is the only one within the Rattendorf Group and thus the youngest fossil flora of the Late Paleozoic sequence in the Carnic Alps.

Flora of the Bombaso Formation

From the Bombaso Formation 3 localities containing plant fossils are known (Tomritsch 1, 2 and 6). The lowermost locality (Tomritsch 6) is characterized by the occurrence of *Sphenophyllum oblongifolium*, *Linopteris neuropteroides*, *Neuropteris ovata*, *Neuropteris scheuchzeri* and others (Fritz & Krainer 1995). According to Wagner (1984) *N. scheuchzeri* is a guideform of the Cantabrian (*Odontopteris cantabrica* zone). This correlation quite precisely corresponds with fusulinid data, which suggests for Cantabrian Uppermost Moscovian and Early Kasimovian age (Ginkel 1971; Rauser-Chernousova & Scherbovich 1974).

Flora of the Auernig Group

From the Auernig Group plant fossils are known from many horizons within all formations. The

lowermost horizon containing plant fossils is from perhaps the basal part of the Meledis Formation (localities Tomritsch 3, Zollnersee and Straniger Alm). The fossil assemblages of these localities are characterized by the abundance of *Linopteris neuropteroides*. The presence of *Sphenophyllum angustifolium*, *S. oblongifolium*, *Callipteridium pteridium*, *Odontopteris brardii* and *Pecopteris* species of the group *P. arborescence -P. schlotheimii* indicates Stephanian age (early to middle Stephanian C according to the megaflora zonation of Wagner 1984). However, there is a contradiction between fusulinid and floral dating of the lower Meledis Formation. Based on fusulinids the lower Meledis Formation is Early to Middle Kasimovian in age and should correspond at least with the upper portion of the Cantabrian, Stephanian A and perhaps Stephanian B (Wagner & Winkler-Prins 1985; Davydov 1990). Only the uppermost Meledis Formation, which contains early Gzhelian fusulinids, could correspond with Stephanian C. The age of the Meledis Formation in the Tomritsch 3, Zollnersee and Straniger Alm localities should also be dated by fusulinids.

The uppermost portion of the Auernig Group containing plant fossils lies within the upper part of the Carnizza Formation (locality Schulterkofel). From this locality Fritz & Boersma (1981, 1983) Fritz *et al.* (1990) described a flora composed of 30 taxa, characterized by the occurrence of *Callipteridium gigas*, *C. pteridium*, *Odontopteris alpina*, *O. brardii*, *Pecopteris feminaeformis* and index fossils for Late Stephanian age: *Aphlebia elongata*, *Pseudomariopteris busquetii* and *Sphenophyllum alatifolium* (*Sphenophyllum angustifolium* zone, Stephanian C according to Wagner 1984).

Flora of the Grenzland Formation

The flora of the Grenzland Formation contains 16 species including *Annularia sphenophylloides*, *A. stellata*, *Sphenophyllum* cf. *angustifolium*, *Callipteris conferta*, *Odontopteris brardii*, *Pecopteris feminaeformis* and *P. schlotheimii*. The occurrence of *Callipteris conferta* and *Sphenophyllum* cf. *angustifolium* indicates Early Permian age (*Callipteris conferta* zone according to Wagner 1984).

Typical guideforms of the *Lobatopteris lamuriana* zone (Barruelian) and *Alethopteris zeilleri* zone (Stephanian B) have not been discovered till now.

According to the plant fossils the Bombaso Formation is of Cantabrian age, the Auernig Group contains typical guideforms of Stephanian C, and the Grenzland Formation is characterized by a flora of Early Permian age (see Table Carnic Alps, this volume). Based on Donets Basin data (Davydov 1990) Stephanian A corresponds to the middle and perhaps part of late Kasimovian, Stephanian B corresponds to the late Kasimovian and Stephanian C to the most part of Gzhelian. Autunian begins from the *Schwagerina robusta-Ultradaixina bosbytauensis* zone of the Orenburgian and also corresponds to the whole Asselian (Fig. 6).

The flora of the Bombaso Formation, Auernig Group, and Grenzland Formation is well dated by fusulinids. Fluvial sequences of the Eastern Alps (Stangnock Formation, Gurktal Nappe), which contain a similar assemblage of plant fossils ranging from the *Odontopteris cantabrica* zone to the *Callipteris conferta* zone, can be well correlated with the marine sequence of the Carnic Alps (Bombaso Formation-Grenzland Formation).

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